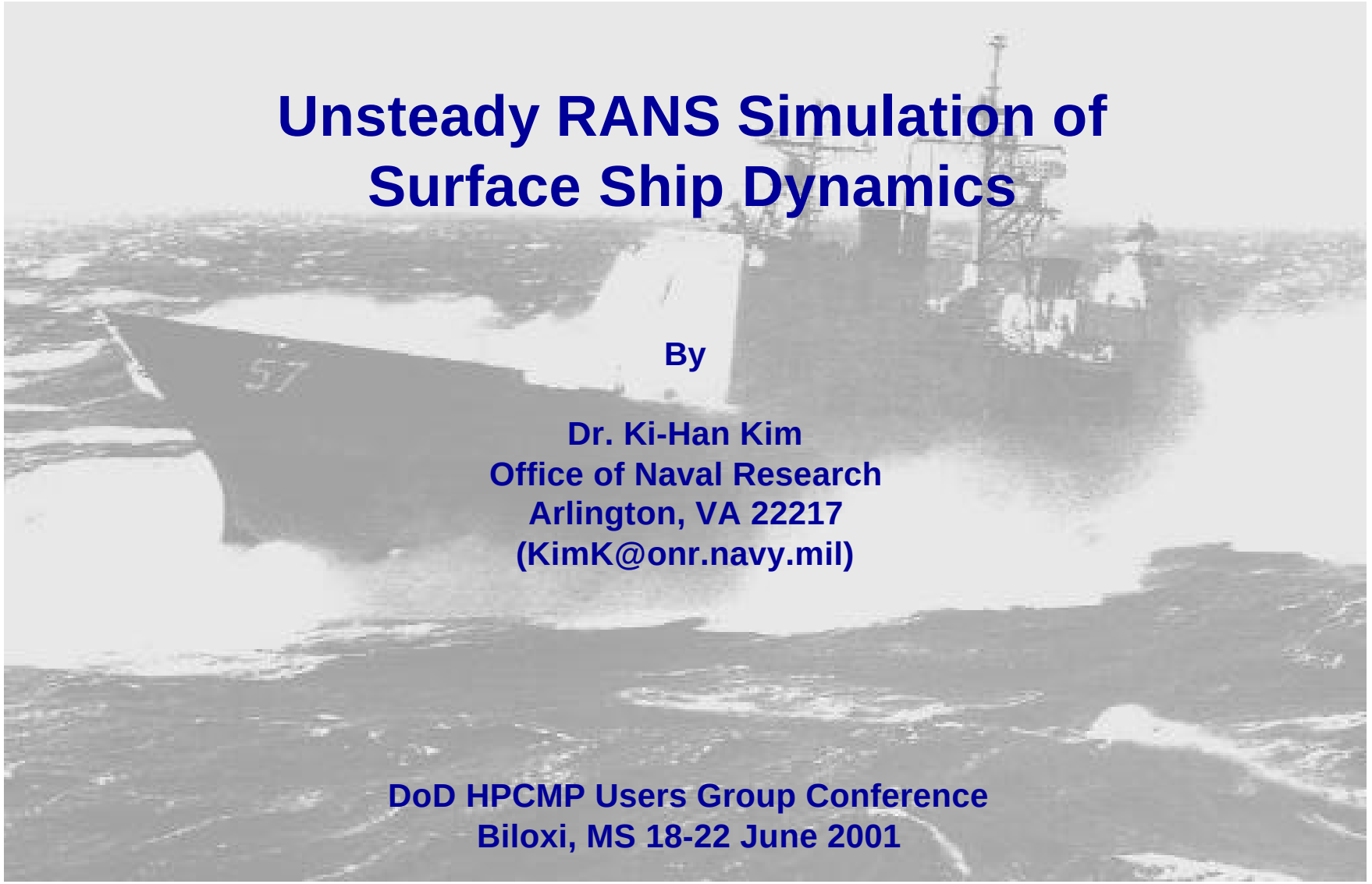
FY2001 Start Challenge Project



Unsteady RANS Simulation of Surface Ship Dynamics

By

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Challenge Team Members

- Office of Naval Research
  - Dr. Ki-Han Kim (Team Leader)
- Naval Surface Warfare Center, Carderock Division
  - Dr. Joseph Gorski and Mr. Ronald Miller
- Mississippi State University, Computational Simulation and Design Center (SimCenter)
  - Dr. Lafe Talyer and Mr. Stephen Nichols
- University Iowa, Iowa Institute of Hydraulic Research (IIHR)
  - Dr. Robert Wilson, Dr. Eric Paterson, and Prof. Fred Stern
- Naval Surface Warfare Center, Coastal Systems Station, Panama City
  - Dr. Mark Hyman

Presentation Outline

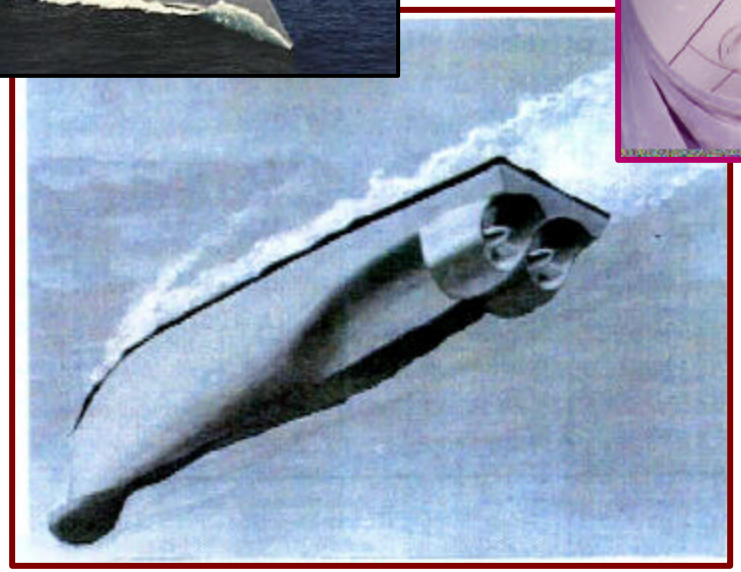
- Objectives and Payoffs
- Challenges and Approaches
- Computational Tools
- Viscous Roll Motion
  - 3-D Cylinder with Bilge Keels
  - Wigley Hull at Zero Forward Speed
  - Model 5415 with Forward Speed
- Model 5415 Steady Turn
- Maneuvering Simulation of Fully-Configured Model 5415
- Future Efforts

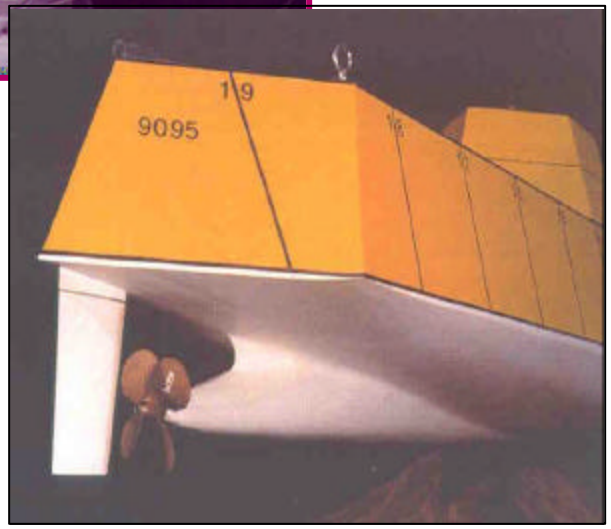
Objectives and Payoffs

- **OBJECTIVE**:
  - Demonstrate the capability to simulate time-dependent six-degrees-of-freedom (6-DOF) motions of ships in waves and the associated near-field flow using unsteady (time-accurate) Reynolds-Averaged Navier-Stokes (RANS) codes.
  - Provide most advanced S&T tools into acquisition and fleet application as alternative to current highly empirical based tools.

- **PAYOFFS**:
  - Significantly reduce the developmental cost of new hull forms by reducing the number of model tests and design cycle time

Future Surface Combatants?





Challenges and Approaches

- Technical Challenges
  - Prediction of high-Reynolds number turbulent flows to adequately simulate the interaction of large-scale waves and ship motions with small scale turbulence and hull flow field
  - Computation of nonlinear turbulent free-surface flow around a ship hull

- Approach
  - Unsteady (Time-Accurate) RANS code calculations
    - UNCLE & U^{2}NCLE developed at MSU
    - CFDSHIP-IOWA developed at Univ. of Iowa
  - Demonstration for roll motions
  - Turning motions for Model 5415

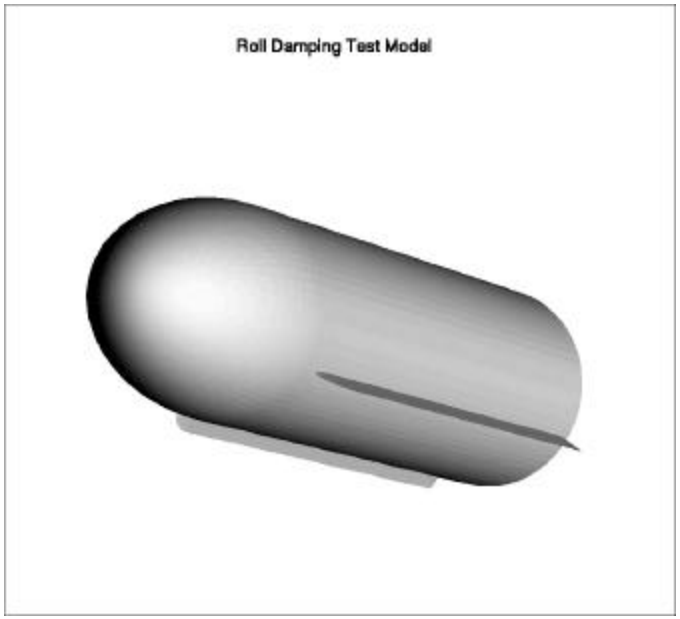
Computational Tools (UNCLE & U^{2}NCLE)

- UNCLE and U^{2}NCLE
  - Developed by Mississippi State University, SimCenter
  - Multiblock, structured grids with arbitrary block connectivity (UNCLE), and multielement unstructured grids (U^{2}NCLE)
  - Scalable parallel algorithm[MPI]
  - Characteristics-based finite-volume spatial approximations
  - Implicit numerical flux linearizations with Block-Jacobi Gauss-Seidel relaxation
  - Nonlinear free-surface capability
  - Boundary layer elements: tetrahedral and multielement meshes
  - Isotropic elements: ALFR (Advancing Front/Local Reconnection) method
  - Geometry and grid generation: SolidMesh with AFLR surface grid generation
  - One- and two-equation turbulence models
  - Highly portable to various platforms

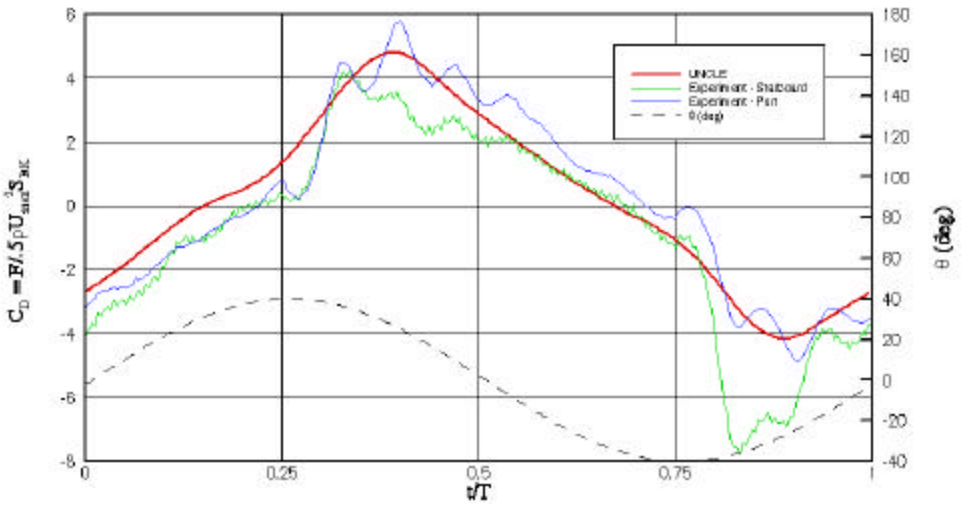
Computational Tools (CFDSHIP-IOWA)

- CFDSHIP-IOWA
  - Developed by University of Iowa, Iowa Institute of Hydraulic Research
  - Fortran 90/95 with modular, open-source architecture
  - Scalable, parallel, portable, multiblock, structured grids with arbitrary block connectivity with Chimera overset gridding capability
  - Higher-order finite difference discretization
  - PISO algorithm for velocity-pressure coupling
  - Parallel algorithm: MPI in coarse-grid mode and OpenMP for fine grain loop-level parallelism
  - Characteristics-based finite-volume spatial approximations
  - Numerical flux linearizations with Block-Jacobi Gauss-Seidel relaxation
  - Nonlinear free-surface capability using free-surface tracking algorithm and/or level set technique
  - Blended k-? turbulence model and wall functions for full scale
  - Highly portable to various platforms

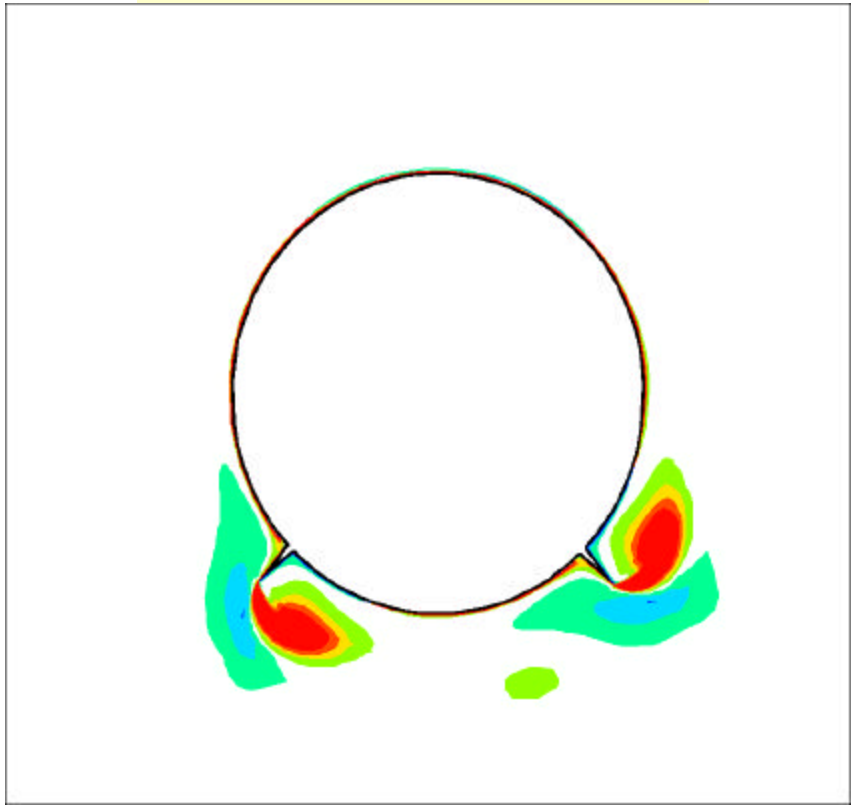
Roll Motions/Bilge Keel Vortices



- D = 35.2 in., Bilge Keel Width = 2 in.
- Time Step: 360/cycle, 6 iterations/time step
- 10 Cycle Solution: 24 hours using IBM-SP3 (84 processors)

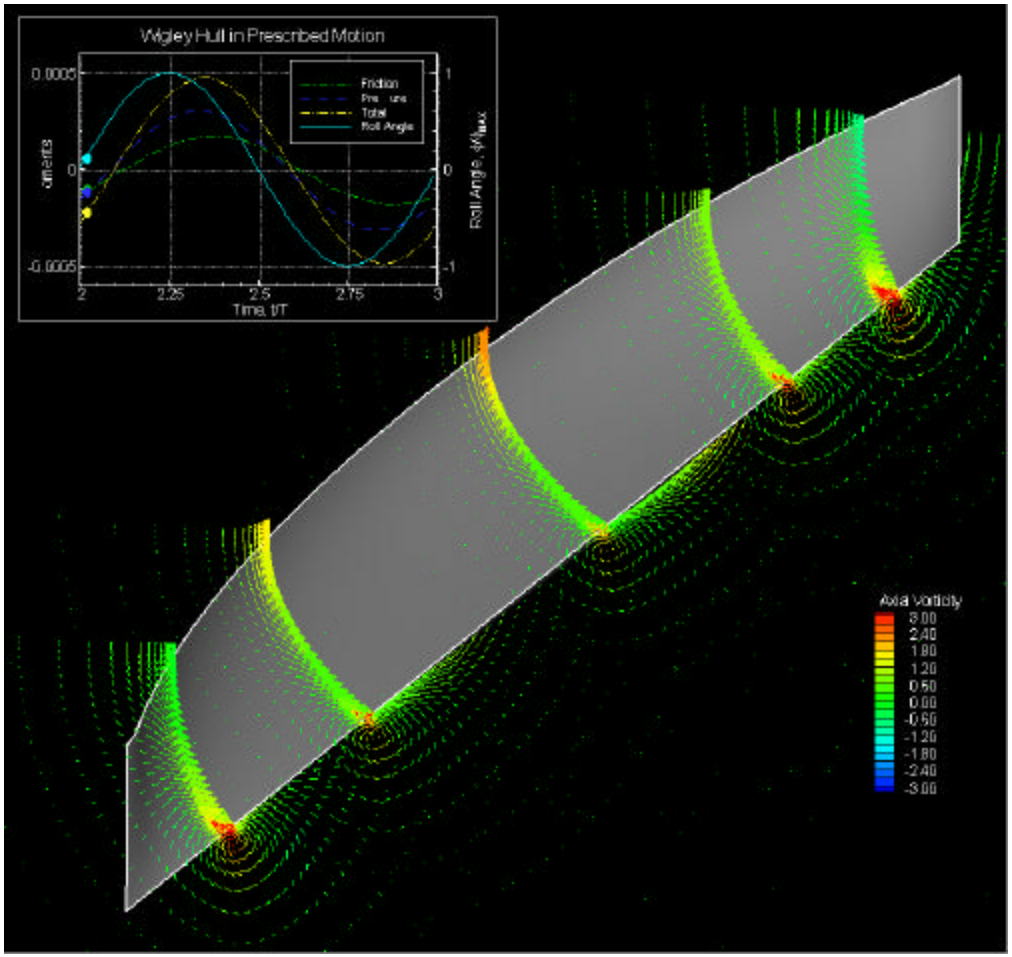


UNCLE with Structured Grid



Wigley Hull at Zero Forward Speed

Computations by CFDSHIP-IOWA



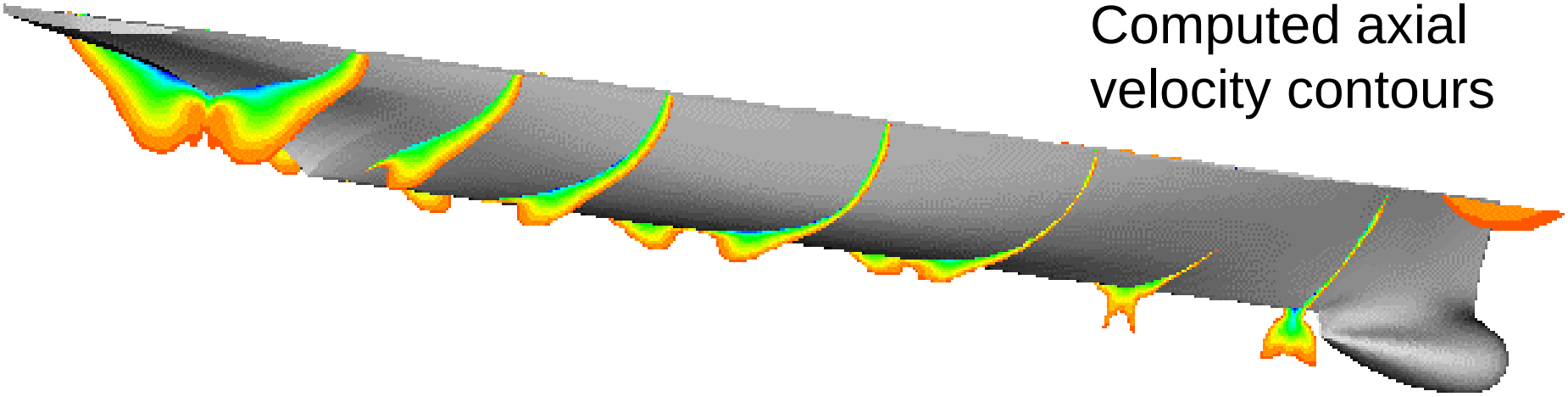
Cross-flow vector and axial vorticity contour

Forced Roll Motion

- SGI Origin 2000 (NAVO) 12 processors
- 4 blocks with 197,000 grid points
- 1-hr wall clock time
- 12 hrs of total CPU for 8 periods of roll motion

DTMB Model 5415 Flow Field

David Taylor Model Basin
Iowa Institute of Hydraulic Research
Italian Ship Model Basin

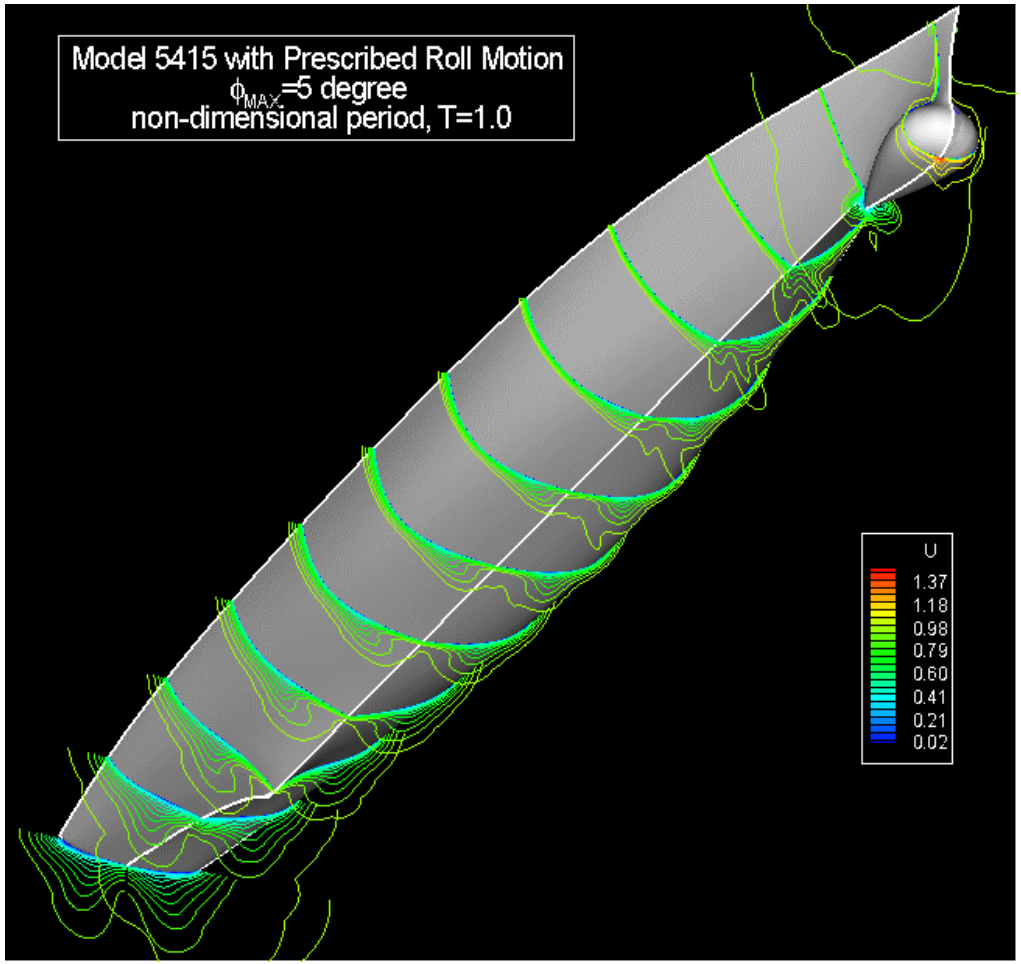


Computed axial velocity contours

Measured data: resistance, sinkage and trim, hull wave profile, near and far field wave elevations, mean flow & turbulence data (pitot probe & LDV) also measure in head waves, and powered with shafts and struts

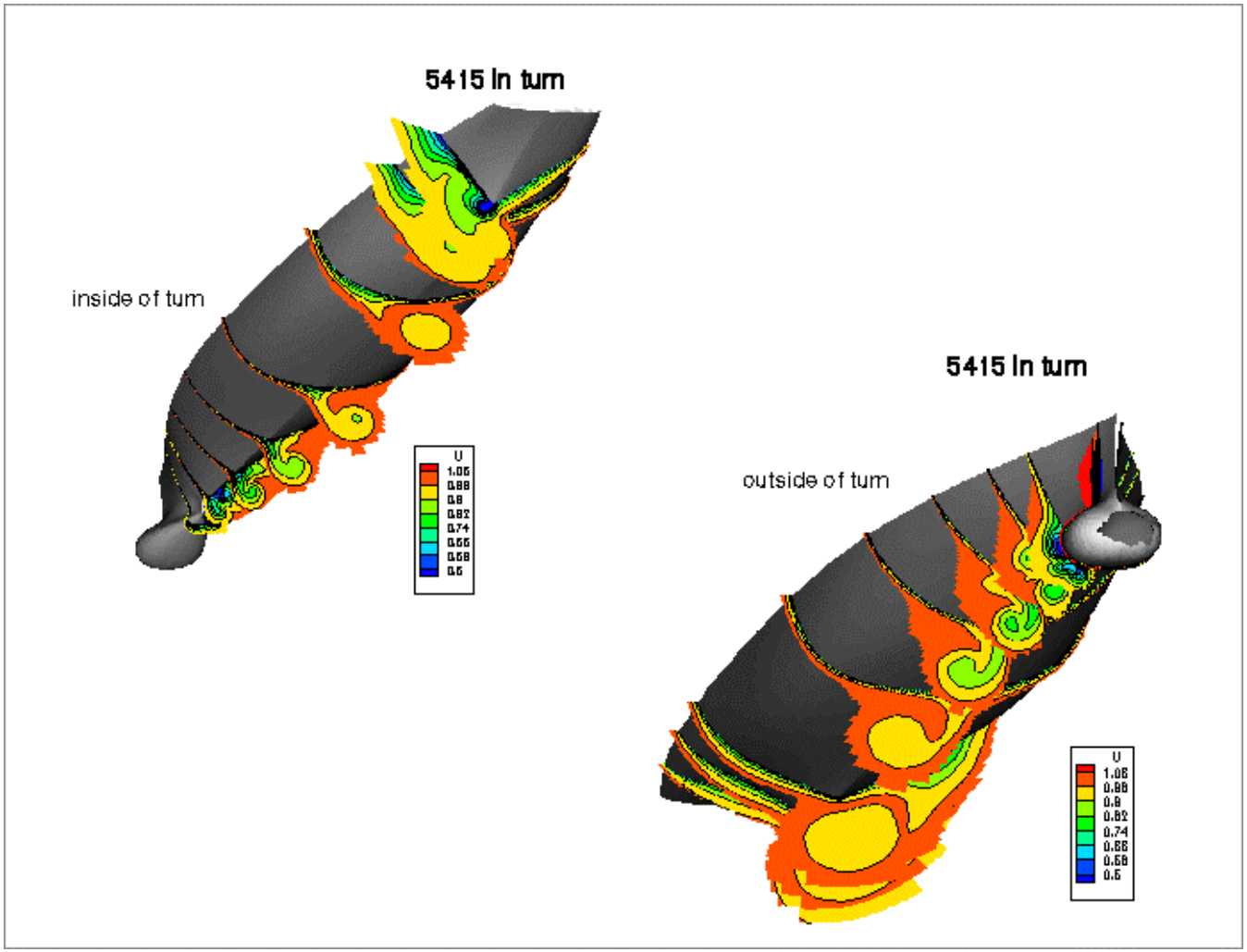
Model 5415 with Roll

Prediction by CFDSHIP-IOWA



- 8-block grid system
- 894,504 grid points
- SGI Origin 2000 at NAVO
  - 20 processors
- 411 total CPU hrs for 4 roll periods

Model 5415 in Turn

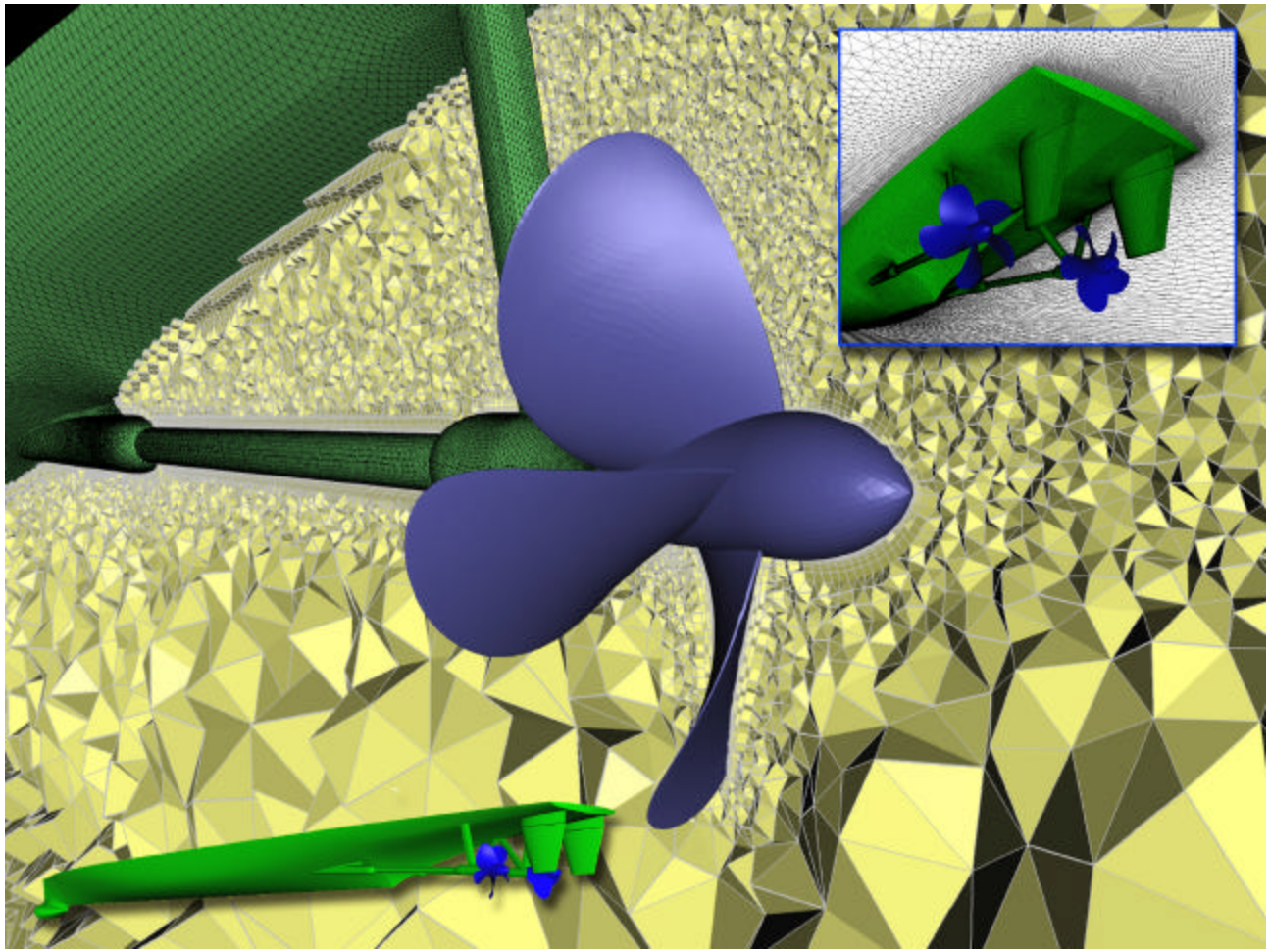


Turning Simulation Using CFDSHIP-IOWA

Turning Condition

- Steady turning diameter: 6 ship lenghts
- Without roll or sideslip
- 6 grid blocks
- 2 million grid points
- Rn = 12 x 10^6

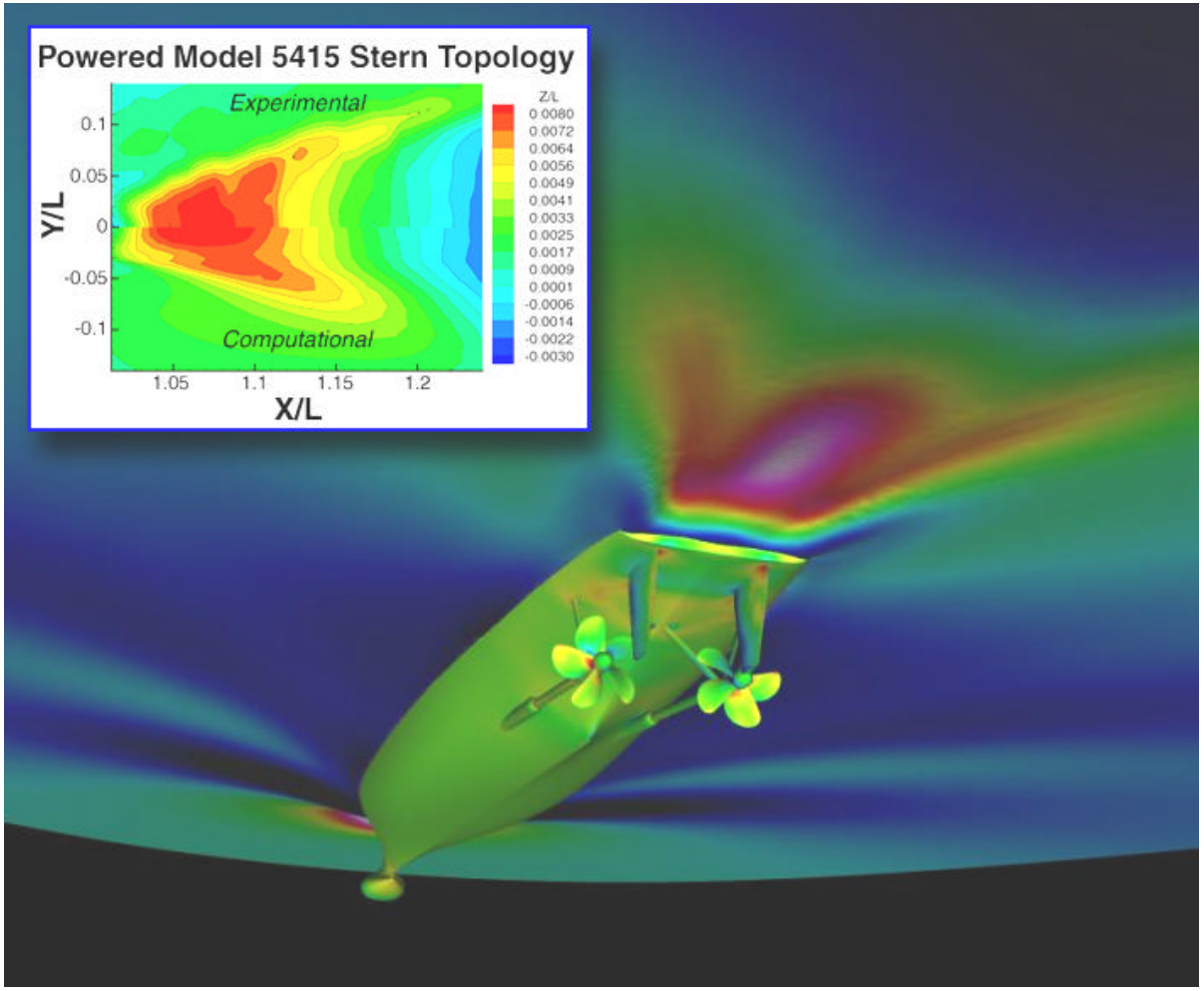
Unstructured Grid for Fully Appended Model 5415



U^{2}NCLE Simulation

- 5.7 million nodes
- 7.7 million prisms
- 9.6 million tetrahedra

Free Surface Elevation and Surface Pressure Distribution on Fully Appended Model 5415



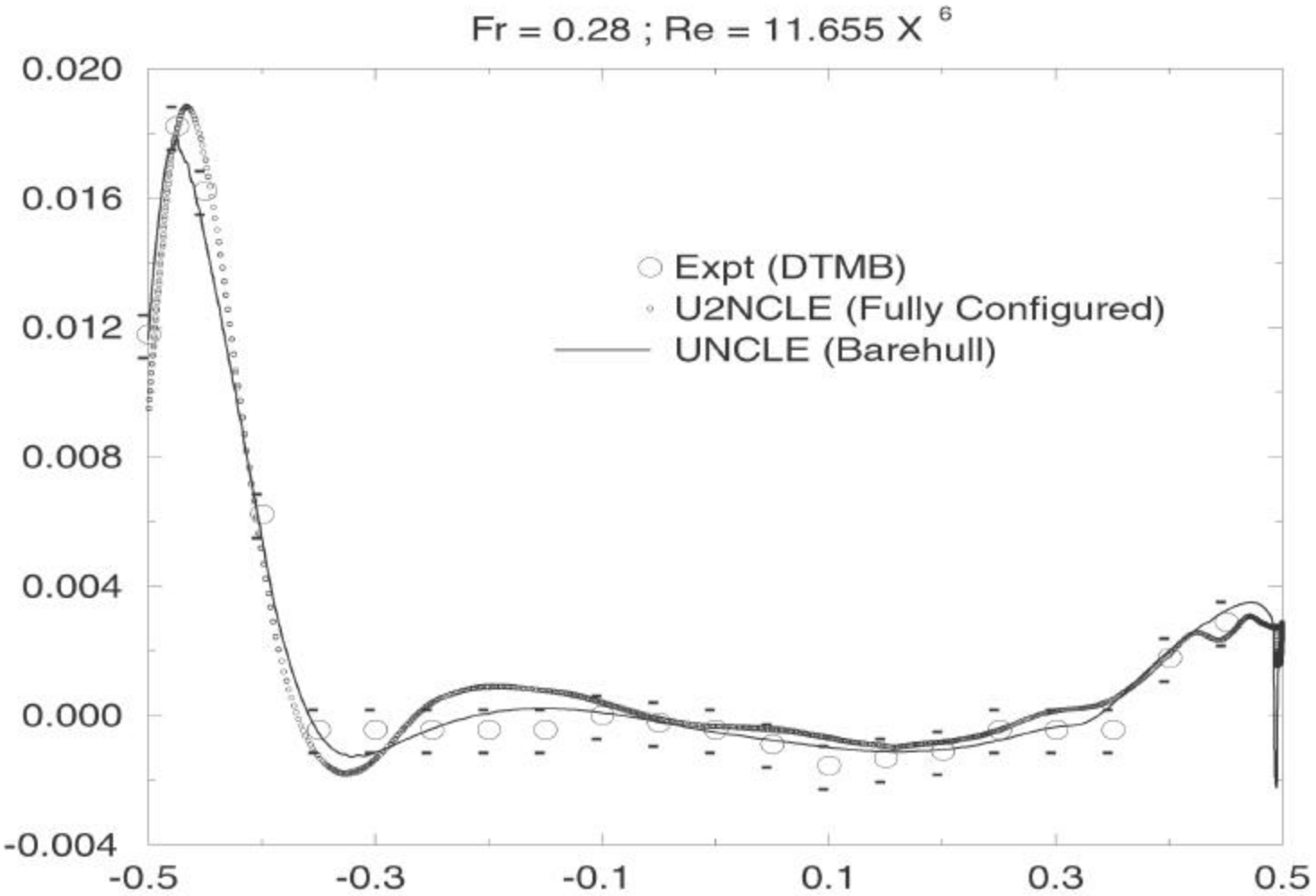
U²NCLE Simulation

- Fn = 0.28
- Rn = 12.02 x 10^6
- Prop RPM = 436
- Straight-ahead

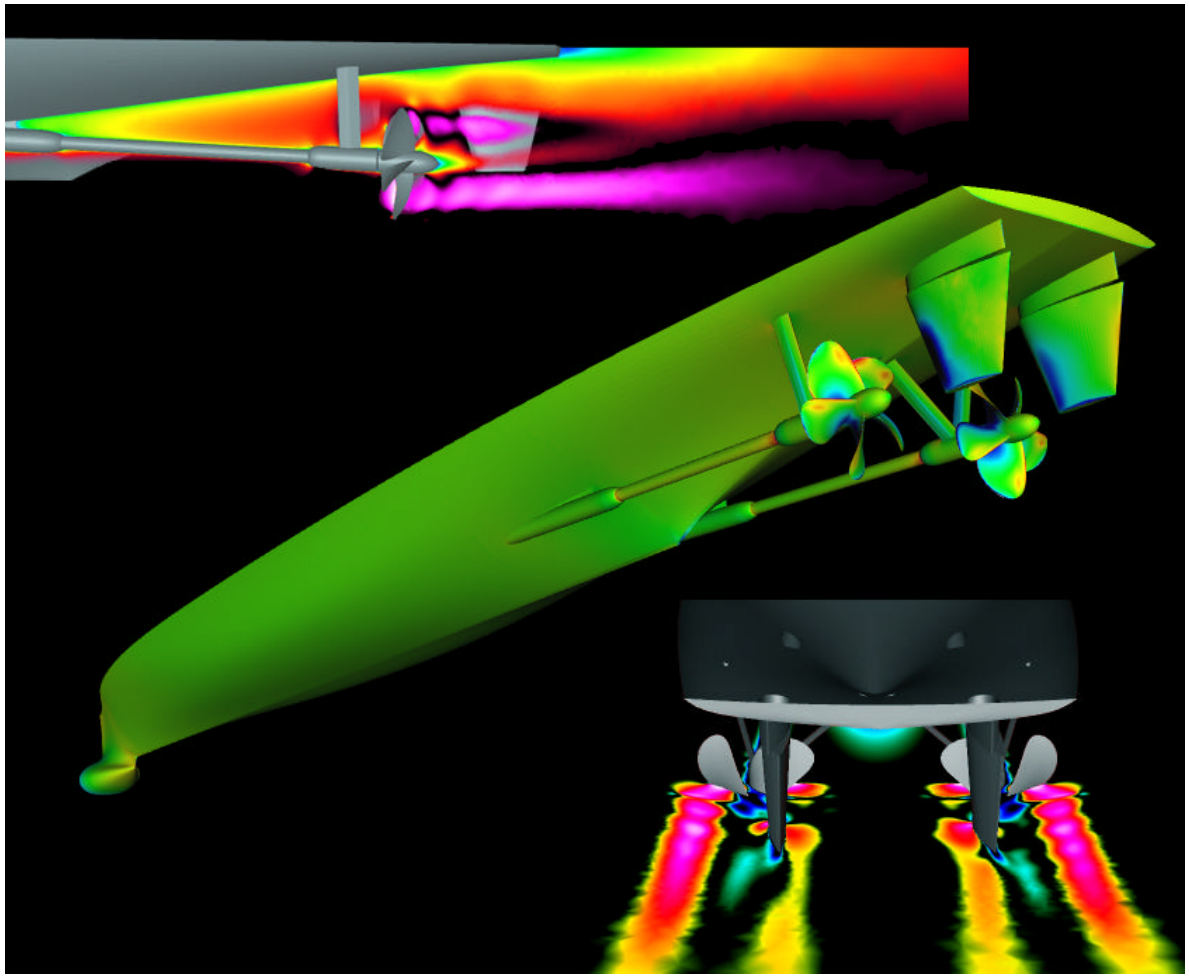
- 5.7 million nodes
- 7.7 million prisms
- 9.6 million tetrahedra

- IBM-SP3 (Maui), 75 processors
- 1440 time step per prop revolution
- Per prop revolution 48 hrs (3600 proc. hours)

Wave Profiles on Model 5415



Rudder-Induced Maneuvering Simulation using U²NCLE for Fully Appended Model 5415 in the Horizontal Plane (3-DOF)



- Top: Axial velocity contours on vertical cutting plane
- Middle: Pressure distribution on hull, propellers, and appendages
- Bottom: Axial velocity contours on horizontal cutting plane

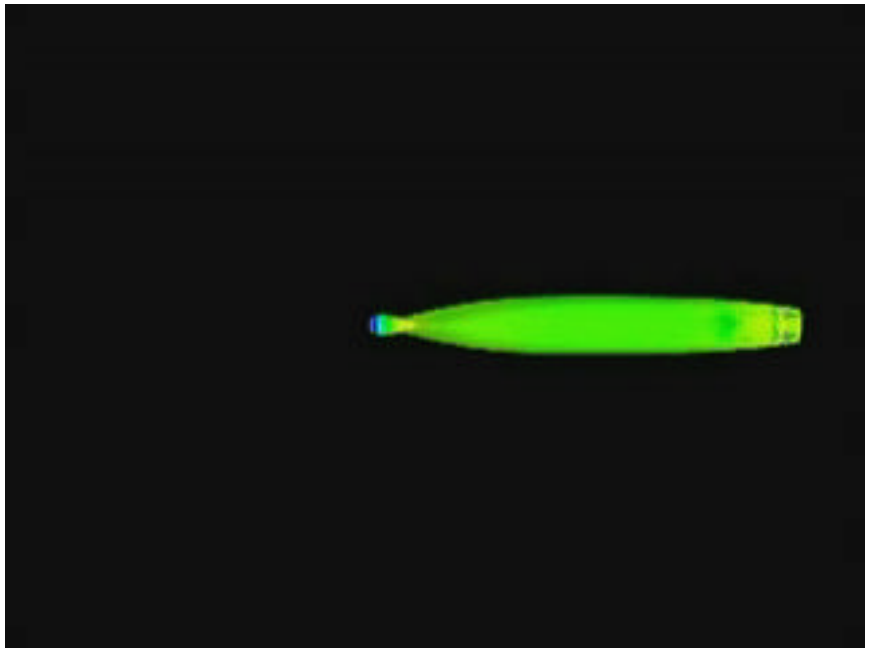
U²NCLE Simulation

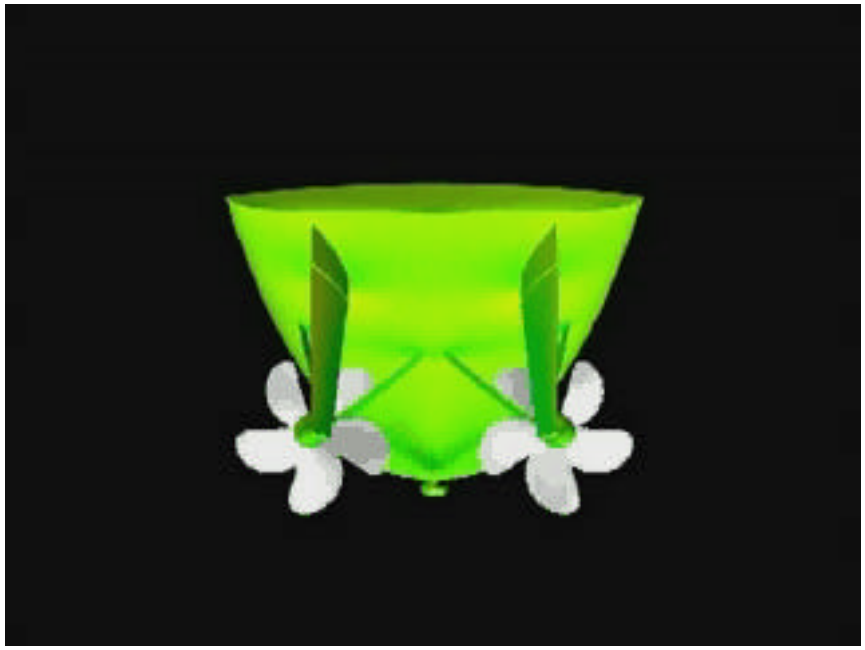
- Fn = 0.0 (3-DOF)
- Rn = 12.02 x 10^6
- Prop RPM = 436
- Rudder deflection rate = 11 deg/sec
- Shown at rudder angle = 6 deg.

- 5.7 million nodes
- 7.7 million prisms
- 9.6 million tetrahedra

- IBM-SP3 (Maui), 75 processors
- 1440 time step per prop revolution
- Per prop revolution 48 hrs (3600 proc. hours)

Rudder-Induced Maneuvering Simulation using U²NCLE for Fully Appended Model 5415 in Horizontal Plane (3-DOF)





Future Plans

- FY2001
  - Roll motion of cylinder with free surface effects
  - Full scale DDG-51
- FY2002
  - Roll motions in head waves
  - Maneuvering simulation with free surface effects
  - Full scale DDG-51 propelled
- FY2003
  - Maneuvering simulation with waves